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Case Study Failures of Buildings Constructed in The Geological Environment of Tuffs

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Abstract

Objective of case studies is to demonstrate the specific character of the buildings, which are not built by using traditional construction materials. They are excavated into the geological environment as the caverns. These specific structures have a specific building construction, but they also tend to be violated by any other way than in conventional constructions. We use the geological environment in its initial in-situ form, which we are not changing. Into this environment, we are creating cavities. They usually have the same morphology as conventional buildings. Violations of these buildings have its specificity. Geological processes that led to the creation of the environment for future construction, this environment, subsequently violates. This is a tectonic process, gravity, earthquake and erosion. The case study was carried out on the church Karanlik in the region of Cappadocia in Turkey. One part of the church is fully maintained with original paintings. The second part of the church was completely destroyed. At the same time there is seen a gradual violation of the church in its preserved parts.

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Keywords: caverns; tuffs; fault structures; geodynamic processes.

1. Introduction

Buildings constructed in a natural environment, representing tuff, they create very specific construction conditions. Conditions for construction of tuff material are determined by a unique geological environment. In the vicinity of active volcanoes, which spewed pyroclastic material, there was deposit of volcanic ash. This created favourable conditions for the formation of cavities. These were formed both natural and anthropogenic activities. An example of such region is Cappadocia. It is geologically and historically significant area, located in the central part of Anatolia in central Turkey. Due to its unique conditions was inscribed on UNESCO World Heritage List. The area is interesting by the conditions of formation and erosion activities. It created a relief in its present form, but also a unique construction activity, which was created tens of meters underground. Tuff material properties help to preserve valuable

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historical paintings in the form of churches and original frescoes. Continued weathering processes create a big problem. This further leads to distortions of rare natural-anthropogenic architectural monuments. Construction advantages of tuff material are known, but in terms of hundreds of years leads to its gradual disintegration. This is evident when looking at the church Karanlik but also many others.

Tuff material was deposited due to volcanic activity of the nearby volcano ErciyesDagi, which is now an extinct. Cappadocia lies west of the central Anatolian Fault. Volcanic activity occurred in result of the collision of African-Arabian and Eurasian plates. Many authors have engaged in exploration tuff material in this area [23][21][25].

2. Creation and exploitation of natural construction and geological environment and its principles

1.1. A source of construction material

Suitable conditions for side-effects, which include volcanic activity, were created by the movement of tectonic plates and creating faults in the territory. Collision African-Arabian and Anatolian plate occurred to the eruption of stratovolcano Erciyes Dagi (Fig. 1a). It completely changed the character of the original landscape and covers the existing geology. Volcanic ash was formed by clastic material of tuffs and it was transmitted to many kilometres. It was gradually imposed (Fig. 1b). Tuffs were covered lava flows, representing a resistant layer (Fig. 1c).

Geodynamic processes intensely disturbing the newly formed relief. It modelled completely different morphology and exposes the great part of the territory (Fig. 1d). This is mainly due to exogenous factors. This leads to significant temperature fluctuations within the summer and winter months. In Cappadocia there is a continental climate. Winters are cold with occasional snowfalls. The summer is dry and hot. The effect of wind, rain, snow, alternating cold and heat leads to erosion of the rock environment. Rocks are expanded, contract at and subsequently lead to their disintegration.

Size of the rock erosion depends on the resistance of rocks. Less resistant rocks lying down. More resistant rock located above them. Erosion modelled shapes resembling towers or also mushrooms, columns, chimneys, pillars and cones, which rises to a height of about 40 meters. The upper part that is constituted by lava flows slower erodible and creates significant cap. In some places the tower or mushrooms are completely separated, or conversely continually follows upon each other. There would create large caverns inside the rock mass (Fig. 1e). These spaces become a refuge soon as the first settlement of the area and the basis for building settlements and monasteries (Fig. 1f).

Volcanic rocks of Cappadocia are represented rocks from the Neogene to Quaternary period. Variability of volcanic material is significant both in vertical and horizontal directions. Generally, the rocks are pale to white, gray and pink, fine-grained to coarse grained.

Volcanic material comprises particles of pumice stone and obsidian is welded tuff and the locus of clay and clay positions salivate. Tuff rocks are mainly composed of quartz and kaolinite. There occur also rocks as smectite, illite, jarosite, sanidine or calcite [4].

Thermal insulation properties of tuff rocks are favourable. Temperatures do not fluctuate significantly due to the outdoor temperature.

In the publication by [1], it was found that the material of Cappadocia tuff has a high porosity and very low weight of the dry sample. It was also shown that the susceptibility of materials to weathering is high under the influence of atmospheric precipitations (Fig. 1g). This affects high porosity largely allowing water infiltration and leads to formation caverns. Compressive strength is low. Although it is an intact rock mass, strength is low. The material properties are not much different in the vertical and horizontal directions. Properties of tuff material are locally different. For example, tuffs of Zelve Avanos are more susceptible to swelling than tuffs of Ürgüp and Derinkuyu.

Solid bedrock is composed of gabbro, pyroxenite, syenite and monzonite, above them is altered red mudstone, and conglomerates [19].

The settlement of this surface has occurred both because of the possibility tuff material, but also the soil fertility. This was caused by enriching the soil through lava. The entire area covers about 300 km^2.

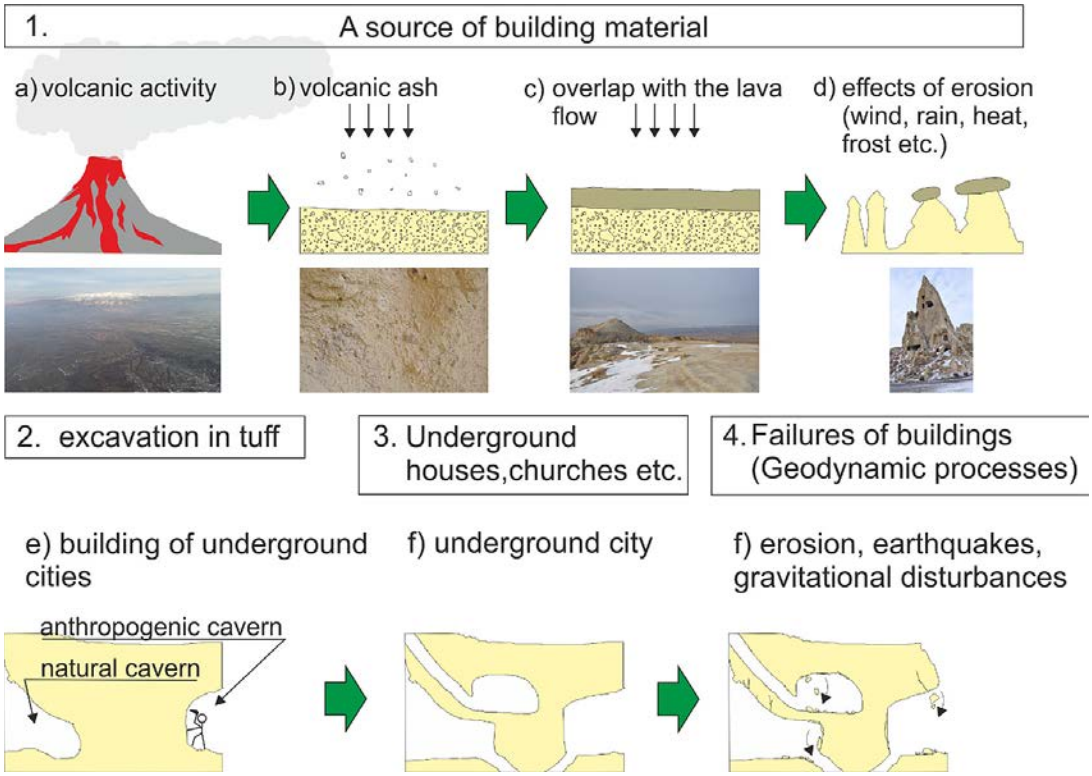

Fig. 1. Source of construction material kicked up from the volcano Erciyes Dagi.

1.2. Buildings created excavation

Excavated corridors and cloisters are very valuable evidence of past civilizations skill and remarkable evidence of the former architecture built underground. Evidence of the presence of the Hittites was dated back to 2. to 1. millennium before Christ.

Light andesitic tuff was easily mineable but also solid. In the middle Ages and Antiquity, it was a very valuable building material not only on the territory of Turkey. Today, it is not so appreciated. This is evidenced by a series of narrow walls that connected the individual rooms and hallways. Monasteries and chapels are very valuable preserved monuments. There is concentrated the largest number of these buildings in Göreme. This is thirty churches. They were excavated into the soft volcanic material. Workability of various rock types are also discussed [8]. Machining tuffs was fast even when using very primitive tools. Construction of any city is also dependent on transportation and developed infrastructure [18].

Tuff material characteristics were very valuable as a building stone. Monasteries had high ceilings; they were wide and very stable for centuries. The current use of underground space precedes the complex mathematical and physical analysis [2][16][15] and [5]. Material used for the construction of these cities can also be seen in terms of mining activities. In this context raises a number of problems associated with the area affected by mining [27][11].

The most valuable is the church Karanlik. It is called the Dark Church. It dates from the 12th and late 13th centuries. Entrance to the monastery is on the front side, a massive rock wall. Part of this huge massif is also other churches excavated in Göreme. The church includes one main apse, two small apses and four columns. Columns have the function of decorative rather than supporting. Churches in Göreme date from the Byzantine Empire. Colonization of the Byzantine Empire also examined [13]. These Christian shrines contain many Byzantine artefacts. The frescoes depict Old and New Testament and the life of Jesus Christ.

The frescoes show the last scene from the New Testament, Nativity of the Lord, Adoration of the Magi, the Last Supper, the Crucifixion and more. Scenes from the New Testament among the best preserved in the entire Cappadocia although the church was damaged both a human hand and natural erosive action. The amount of light entering into the church is very limited. This is due to the existence of a small window called Oculus, away from the narthex. Lack of sunlight into the space of the church has kept the density pigments for centuries.

Fig. 2 Internal part of the church Karanlik (mined cavern) with original paintings from the 12th century. The view from the narthex.

Narthex is typical for Byzantine churches. They are composed of an entrance area and opposite the main altar. Space with four equally long arms, which is vaulted with a dome, is typical for Byzantine architecture. Frescoes figure from this period makes a stiff, unnatural. Their purpose is to introduce supernatural looking of mortal.

Entrance to the church Karanlik is from the north. In the central dome is shown Pantocrator Jesus. In four small domes are represented Archangels. North apse is painted on a blue background, there is painted the mother of Mary and Jesus. On the south apse is Abraham.

The main apse was painted using the technique of painting directly on wet plaster. It was very rare in churches in Capadocia. There are even see fingerprints from artists on the face of Jesus, Mary and John the Baptist. The church was built with eight sponsors who are portrayed in the church. Two are in the apse, two in the narthex and four are near the archangels. The position of drawings is the rarest sites of the church [6].

Among the important frescoes also includes four evangelists. They are painted on the north and east of the church. Doctors Domian and Cosmas they were painted with medical instruments in the hands of the northern wall. Churches in Cappadocia also dealt [20]. Today's appearance of the frescoes was adjusted by restorers. Colour density was restored.

1.3. Construction failures caused geodynamic processes

Figure 3 shows a failure in tuff rock material on the walls of the church Karanlik. The structure of the rock mass is determined by the shape, size, spatial arrangement of the rock bodies and blocks, which are limited by discontinuities. Discontinuities may have lithological character, mechanical, or physical with different genesis. Discontinuities may have been created since the genesis of the rock mass or may occur later.

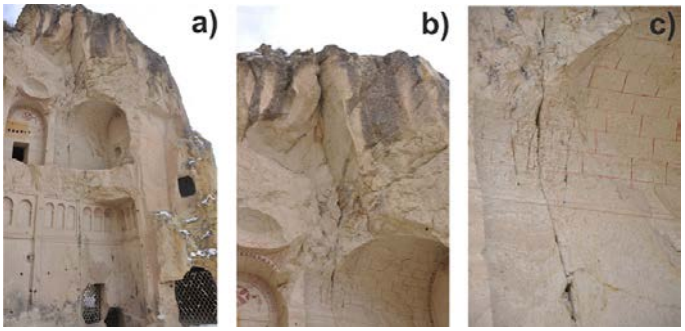

Fig. 3. Detail of the fault structures on the church Karanlik - a crack in the tuff material:
a) ruined part of the church, b) crack in the upper part of the church, c) detail of crack.

There are discontinuities caused after the genesis of rock massif, in the case of the said church. They are caused by weathering processes. These are mainly mechanical and physical disorders. This is a long-term effect of exogenous factors and the effects of gravity that is the weight of the overlying strata. The area is tectonically still active. It plays an important role in the formation of cracks. Behaviour of ground mass in Cappadocia also examined [12] in connection with the effects of an earthquake.

Implementation of underground cities is conditioned integrity of the rock mass [26]. Discontinuity in the tuff material in the church Karanlik can be divided into incomplete. They are not an obvious breach of continuity. The second group consists completely discontinuity. There it is already evident that the ultimate strength of rocks was exceeded. The stability of the rock mass depends on the frequency of cracks, their orientation, size of the gap, eventually filling. The size of gap cracks is in the order of mm to tens of centimetres. The Cracks have mostly continuous character, thus they violate building across and can be described in the order of one to several meters. Wall cracks are uneven, rough and bumpy. It is determined with the tuff material in which cracks occur. This provides greater stability of cracks and there is some limitation of any sliding surfaces.

The Cracks are filled with new material, which could act as a binder. The ceiling of the entire massif is composed of basaltic layer. This represents a stronger and more resistant packaging, creating a protection against the formation of discontinuities. That is not in the case of its exposing, which are less resistant tuff material exposed to exogenous factors in the lower part. Authors [14] dealt with discontinuities in tuff rocks with the help of feedback analysis. Also in the work [22] were examined for discontinuity tuff chimneys.

Part of the church Karanlik completely collapsed. In study [3], it was found that the speed of weathering is between 0.03 and 0.59 mm / year for more resistant Esbelli tuffs and 0.4 and 2.5 mm / year for Kavak members. The publication is also based on the knowledge, mentioned in [17][10][14] and [7].

3. Conclusion

Cavern structures represent a special category of buildings in easily quarried rocks. Their specification is special both in terms of building material, which is composed of rock massif, and in the case of building failures occurring in them. Disorders buildings raise more factors than with conventional construction systems. Weight structural system is not composed of only construction material as in conventional constructions. It is formed the entire rock mass, in which the building is constructed. Especially if the rock mass is separated from the surroundings erosion walls. This means that there is no transfer of load to the surroundings. The weight of the overburden is only transmitted from the upper floors to the bottom of these towers of erosion. Susceptibility to failure is greater if here are cracks loaded by climatic conditions (water, wind, freezing etc.). While the base of erosion towers in the space of less than susceptibility to failure and collapse of cavities is greater. Another important factor is the nature of discontinuities that violate the rock mass in the round of caverns. Vertical open cracks are especially dangerous because they are most likely to cause the collapse of the construction. Sloping vertical cracks are also dangerous but it depends on their continuity. When it is more continuous, they are more dangerous from the perspective of building failures. The influence of the earthquake

is a significant factor in the Cappadocia region. There is a tectonically active zone visible at the contact of the Arabian Plate and the Anatolian plate. Due to the 800 to 900-year history of the church there is evidence that tectonic danger took place more than once. It had a negative impact on the danger of building. Water penetrated along the vertical cracks into the rock mass during precipitation. This caused freezing and thawing in the winter and it was destructive.

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